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RESEARCH MEMORANDUM

EFFECTS OF RESIN COATING METHODS AND OTHER VARIABLES ON PHYSICAL PROPERTIES OF GLASS-FABRIC REINFORCED POLYESTERS

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National Bureau of Standards

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SUMMARY

The effects of resin coating methods upon some physical properties of laminates prepared with glass fabric, Fiberglas 181, and bonded with two commercial polyester resins were investigated. The resins used were Laminac 4126 and Selectron 5003. Fabric with finishes 111, 112, and 114 was used in making laminates with the Laminac resin. Only fabric with finish 114 was used in making laminates with the Selectron resin. The resin coating methods used were (1) roller coating, (2) application of a dilute solution of resin, (3) resin immersion, (4) application of monomeric styrene, and (5) vacuum impregnation.

Two curing conditions were used: (a) A normal high-temperature short-time cure and (b) a moderate-temperature long-time cure. The preparation of these laminates was carried out according to a statistical design to minimize the influence of uncontrollable variables such as aging of resin and batch of resin. The laminates were tested for flexural strength, both dry and after 7 days' immersion in water; resin content; specific gravity; and percentage of voids. Percentage loss of strength due to water immersion was also calculated.

No consistent effects of coating methods on the strength of the laminates bonded with Laminac 4126 resin were observed. With Selectron 5003, use of a dilute solution of resin produced laminates that were lower in both dry and wet strength than laminates made by the other methods. Some interaction between coating methods and temperature of cure was observed with Laminac 4126 resin. For laminates made by resin immersion and by vacuum impregnation the dry strengths were essentially independent of cure temperature. Except for these instances, the lower temperature produced laminates of higher strength than those made at the higher temperature. The reverse temperature effect occurred in laminates bonded with Selectron 5003. Laminac 4126 laminates made of fabric with finish 114 had higher wet strength and lower loss of

strength due to immersion in water than laminates made of fabric with the other finishes.

INTRODUCTION

The steady increase in the use of glass-fiber reinforced resins in the aircraft industry is ample evidence of the advantages this material offers to the industry. The application of this material in aircraft could be increased even further if better quality control and improvement of some of its properties could be attained.

The investigation described in this report is one of a series undertaken to help achieve this goal. In these investigations an attempt was made to isolate some of the variables in the laminating process which affect the physical properties and the uniformity of glass-fabric reinforced polyester plastics. Previous phases of this program included studies of the effects on the properties of this material of such production variables as molding conditions (ref. 1), fabric finishes (ref. 2), and relative humidity of the ambient atmosphere during fabrication (ref. 3).

In the phase of the investigation described in this report, the effects of resin coating techniques on the physical properties of glass-fabric polyester laminate were studied. These resin coating techniques were based on two fundamental aspects of adhesion: (1) Increasing the wettability of the adherend by the adhesive and (2) elimination of impurities from both adherend and adhesive. Some consideration was also given to the possible effects of the difference in the thermal coefficients of expansion between the glass fabric and the resin. This was done by molding the laminates at two different temperatures. Glass fabric with different surface finishes as well as without finish was used to determine the effects of surface treatment.

The assistance of Mrs. Dorothy C. Pons with the laboratory tests and the calculation of the data is gratefully acknowledged.

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MATERIALS

The glass fabric selected for this investigation was Fiberglas 181 with finishes 114, 111, and 112.

Finish 114 is a solution of methacrylato-chromic chloride. It was chosen on the basis of the manufacturer's recommendation and on the basis of previous work done in this laboratory which indicated that laminates made with this finish had high flexural strengths both wet and dry.

Finish 111 was chosen on the basis of the results obtained in the same investigation, which showed that this finish produces laminates of high dry strength but low wet strength.

Fabric with finish 112 was chosen as the control since it is a heat-cleaned fabric, that is, one without any finish. It was included to determine the effect of the resin coating techniques on uncoated glass surfaces.

The resins selected for this work were Laminac 4126 and Selectron 5003. These were chosen as being typical commercial unsaturated polyester resins. The catalyst was benzoyl peroxide, Luperco ATC, in paste form. This paste catalyst consists of 50 percent benzoyl peroxide in tricresyl phosphate. The cellophane used as a release agent was Sylphrap No. 600 P-1-L.

DEFINITIONS

The following terms are used in this report in accordance with the indicated definitions:

Flexural strength.- The flexural strength S in pounds per square inch for a simple beam of rectangular cross section subjected to a concentrated load at midspan, is calculated as follows:

$$S = \frac{3}{2}\frac{PL}{bd^2}$$

where

P	maximum load, lb
L	span or distance between supports, in.
b	width of beam, in.
d	depth of beam, in.

Resin content.- The resin content is the amount by weight of resin, obtained from weight differences between burned and unburned specimens of the laminate, expressed in percent.

Percentage of voids.- The percentage of voids is the volume of voids V_v in a specimen, expressed in percent of the measured volume V_s of the specimen as follows:

$$V_v = \frac{V_s - V_s'}{V_s} \times 100$$

where

V_s volume of specimen obtained by weighing in water and air

V_s' volume of specimen calculated on assumption of no voids and using measured weight of resin and of glass fabric in specimen and known values of density of glass and resin

EXPERIMENTAL PROCEDURES

Fabrication of Laminate

The laminates were molded between plate-glass platens, 6 by 6 by 1/4 inch. The platens were preheated to the molding temperature before use in the molding operations. The molding pressure was 0.7 psi and was obtained by the use of dead weights. The laminates were cured in two ovens, each of which was kept at a different temperature. The laminates bonded with Laminac 4126 resin were cured at two different conditions, namely, 160° F for 48 hours and 235° F for 2 hours. Those bonded with Selectron 5003 resin were also cured at two different conditions, namely, 105° F for 24 hours and 235° F for 1 hour.

The laminates bonded with Laminac 4126 resin were molded in sets of 30 panels, representing one panel for each combination of fabric with the three finishes, two molding conditions, and five resin coating methods. The order of fabrication within each set was randomized. Triplicate sets of 30 panels were prepared, making a total of 90.

Laminates bonded with Selectron 5003 were made only of fabric with finish 114. A set included one laminate molded at each condition with application of the resin by each of the coating methods. Two sets of 10 panels each were made with Selectron 5003 resin. The fabrics were coated with the resins in a controlled-humidity chamber, approximately

6 by $2\frac{1}{2}$ by 2 feet. The front of the chamber was equipped with a sliding door with the two armholes, to which were attached some flexible vinyl-plastic sleeves to serve as a moisture barrier. The flexibility of the sleeves allowed the operator sufficient freedom of movement to perform the necessary operations. Rubber gloves were worn by the operator to prevent the atmosphere in the laminating chamber from picking up moisture from his hands and arms.

Low relative humidity, 4 to 10 percent, was maintained in the chamber by recirculating the air over trays of silica gel. The silica gel was changed at least once every 8 hours of operation. After several hours of exposure to resin vapors, the silica gel lost a considerable amount of its desiccating efficiency. The efficiency of the silica gel could not be restored by heating.

The laminates were made from pieces of the fabric 6.5 inches square. To keep the fibers of the fabric from unraveling during the resin coating process, the edges of each ply of fabric were coated with starch. Prior to application of resin by any of the five coating methods, the fabric was conditioned for a period of at least 7 days over silica gel.

The resins, Laminac 4126 and Selectron 5003, were mixed with 2 percent of the catalyst in batches of about 300 grams. The mixture of resin and catalyst was stirred with a spatula for 10 minutes before use.

Resin Coating Methods

Five methods of resin coating were employed in this investigation.

Method 1.- Method 1, in which the resin was applied to the pieces of fabric by means of hand-operated squeeze rolls, was selected since it is a technique commonly used in commercial practice. Each piece of fabric was run between the rolls, which were coated with the liquid resin solution, as many times as were required for the piece to lose its opacity. Uniform translucency of the fabric was considered to be the criterion of sufficient impregnation.

The panel assembly was accomplished by pouring a small amount of resin on a flat piece of cellophane and superimposing seven squares of resin-coated fabric on each other over this resin area. A small amount of additional resin was applied to each successive ply as it was added to the assembly. Another piece of cellophane was placed over the top of the assembly. Air pockets were eliminated by pressing a spatula over the surface of the cellophane. This entire procedure was carried out in the controlled-humidity chamber. Complete assembly of a panel was accomplished in about 10 minutes.

After taking the cellophane-wrapped assembly out of this chamber, the ends of the cellophane sheets, which extended beyond the limits of the laminate, were folded over and held in place with paper clips. The lay-up was placed between preheated glass plates, pressure applied, and the assembly placed in a circulating air oven.

Method 2.- The pieces of fabric were coated with resin in two stages in method 2. This technique was adopted to determine the effect of reducing the viscosity of the resin. A lower viscosity would increase the rate of wetting of the surface of the glass fibers and also the flow of resin solution into the interior of each multifilament glass thread. This might result in a more intimate and uniform resin-to-glass contact.

The resin solution was diluted with an equal volume of ethyl acetate and the individual pieces of fabric were immersed in the resin-solvent mixture for 10 seconds. The wet fabric was oven dried in a suspended position for 1/2 hour at 80° C, removed from the drying rack, and placed in the controlled-humidity chamber for at least 15 minutes. An additional coat of resin was applied by repeating this procedure, except that the resin solution was not diluted with ethyl acetate. The final resin-coated fabric was flexible and slightly tacky. The coated layers of fabric were assembled at 5- to 10-percent relative humidity. Assembly and molding of the laminates was accomplished in the same manner as for the laminates made by method 1.

Method 3.- Method 3, which involved an extended period of immersion, was selected to allow for the elimination of air by gravitational force rather than by squeeze rolls which tend to damage the fibers and to distort their orientation.

Seven plies of fabric were stacked together, and the stack was placed in a bath of the liquid resin. The fabric was kept immersed in the resin solution for 24 hours in the case of the Laminac resin, and for 3 hours in the case of the Selectron resin. After completion of the immersion period, the resin-coated stacks of fabric were placed between two pieces of cellophane, pressure was applied, and the assembly was placed in the oven to cure. It was found that the time of immersion was sufficient to allow all visible air pockets to be eliminated and hence further elimination of air with a spatula was unnecessary.

Method 4.- Method 4, which consisted of dipping the pieces of fabric in styrene before applying the resin, was selected because qualitative observations in previous investigations indicated that monomeric styrene wets glass very readily. Since styrene is also one of the components of the resins used, it seemed reasonable that this procedure might produce a resin-styrene combination with better adhesion between the resin and the glass and thus would result in the production of higher strength laminates.

The pieces of fabric were placed in the controlled-humidity chamber in which the relative humidity was about 5 percent. Each piece of fabric was first dipped into a bath of styrene monomer for 10 seconds and then was held in the dry air for an additional 10 seconds to allow the excess styrene to drip off. As each piece of fabric was superimposed on the preceding one, an excess quantity of resin was poured over it. When the lay-up of seven plies was completed, it was wrapped in cellophane, pressure applied, and the assembly placed in the oven to cure.

Method 5.- In method 5 the fabric was coated with resin in an evacuated chamber to eliminate any adsorbed air and other impurities from the surface of the fibers. Partial deaeration of the resin resulted when the resin was introduced into the system while the pressure was low.

The pieces of fabric were placed in a desiccator, the latter was evacuated to a pressure of 0.1 millimeter of mercury which was maintained for 3 hours. A separatory funnel was attached to the top of the desiccator through a rubber stopper. After 3 hours of evacuating, the vacuum pump was shut off and the resin solution, which had been poured into the separatory funnel, was allowed to flow over and completely cover the fabric within the desiccator. The fabric was allowed to remain immersed in the resin for 10 minutes before it was withdrawn from the desiccator. The lay-up was assembled between two pieces of cellophane, pressure applied, and the assembly placed in the oven to cure.

Methods of Test

Eight flexural specimens, 1/2 inch wide and 3 inches long, were cut from each panel. The specimens were machined by dry grinding to a width of 0.500 ± 0.001 inch. Four of these specimens from each panel were conditioned for at least 7 days at 77° F and 50-percent relative humidity before testing. The other four specimens from each panel were immersed in water at 77° F for 7 days and were tested immediately upon removal from the water. The flexural strength was determined according to Method 1031 of Federal Specification L-P-406b (ref. 4).

Specific gravity was determined by the displacement of water technique according to Method 5011 of Federal Specification L-P-406b with four specimens cut from each panel. Resin content was determined by loss upon ignition at 900° F for 1.5 hours with four specimens cut from each panel. A correction was used in the calculations for the loss of fiber sizing due to ignition. This correction, in percent of

the weight of the glass, was 0.6, 0, and 0.3 for finishes 111, 112, and 114, respectively.

The volume of voids was calculated from the density and the resin content of the specimens. The densities used in making these calculations were as follows:

Glass, g/cm^3	2.57
Laminac resin 4126, g/cm^3	1.15
Selectron resin 5003, g/cm^3	1.22

The densities of the resins were determined experimentally on castings of these resins.

The density of the glass was obtained from Owens-Corning Fiberglas Standards PR6·Al-Section II, November 15, 1950.

STATISTICAL ANALYSIS

The data were analyzed statistically to isolate and evaluate the effects of resin coating methods, temperature of cure, and fabric finish. Details regarding the design of the experiment and the analysis of the data are given in the appendix. The discussion in the following section is based on this analysis.

RESULTS AND DISCUSSION

Laminac 4126

The results of the flexural-strength tests on the laminates made with Laminac 4126 are presented in table I. The specific gravities, resin contents, and volumes of the voids of the laminates are reported in table II.

Statistical analysis showed no consistent effect of the method of applying the resin to the fabric on the dry flexural strength of the laminates. Both the wet strength of the laminates and the change in strength as a result of water immersion are independent of coating method.

Within groups of laminates made of fabric with the same finish and molded at the same temperatures, there are no significant differences in the specific gravities of the laminates made from fabrics

coated by the various techniques. No consistent effect of resin coating methods on the resin content of the laminates is observed, except that method 2 produced laminates of slightly but significantly higher resin content. This could be expected since in this method the resin was applied in two coats.

The calculated voids content is lowest in laminates made with fabrics coated by method 2 in which a dilute solution of resin was initially applied to the fabric. Although the voids content of these laminates is calculated to be less than zero, visual inspection of these laminates showed that numerous voids were present. Negative voids contents were also calculated for four other groups of laminates, all of which were molded at the lower temperature. The reason for obtaining these negative values is that the method used in the determination of this property is based on the specific gravity of a cured block of the resin which is not necessarily the value for the resin in the laminate. Some styrene is lost during the resin coating process and during the long curing process, 48 hours at a temperature of 160° F. This loss of styrene was particularly large in laminates made with fabric which had been coated with resin by method 2. Since styrene is the low-density component of the cured resin, a decrease in the styrene content of the resin will result in a resin of higher density than that of the cured block of unfilled resin. This is in line with the observation that, within groups of laminates made of fabric with the same finish and molded at the same temperature, the highest calculated volume of voids usually occurred in laminates made by the initial coating of the fabric with additional styrene.

In view of the unknown bias inherent in the calculation of voids content, as indicated in the preceding paragraph, it is not possible to draw inferences from such data regarding the true effect of resin coating methods on the voids content of the laminates. However, valid comparisons can be made on the basis of these data with regard to the effect of other factors provided that the coating method is unchanged.

Considerable interaction was in evidence between temperature of cure and resin coating methods. For resin coating methods 1 and 2 the lower cure temperature produced laminates of significantly higher dry strength than did the higher cure temperature; for method 4 an effect in the same direction, but smaller, is observed. For resin coating methods 3 and 5 there was no effect of temperature of cure on the dry strength. It may be that, when high-temperature cures result in lower strength laminates, it is partly because of the expansion of adsorbed moisture and air on the glass fibers during the bonding process.

When most of the air and moisture are removed from the glass fibers and the resin, sound laminates with low voids content are produced regardless of temperature of cure for temperatures of 160° to 235° F.

This was partially borne out in an investigation by this laboratory of the effects of relative humidity during fabrication on the strength of laminates (ref. 3); in this work the resin used was also Laminac 4126. It was shown that an increase in the humidity during fabrication decreases the strength of laminates molded at a temperature of 220° F or higher. It was also shown that, even at low relative humidities, laminates molded at 160° F were slightly but significantly higher in dry strength than were the laminates molded at 200° and 250° F.

It might be inferred from the latter that the difference in strength was due solely to the stresses resulting from the difference between the thermal coefficients of expansion of the glass and the resin. The data in table I, however, show that the dry strengths of laminates made with fabric vacuum impregnated with resin were not affected by molding temperature. This indicates that, in the investigation of the effects of humidity, the lower strength of laminates molded at the higher temperatures may be attributed partly to the expansion of the air and moisture adsorbed on the glass and the adsorbed air in the resin, and partly to differential expansion of the glass and the resin (ref. 5).

This evidence suggests that, if the relative humidity were not kept low in all of the resin coating methods, then the laminates made with fabric that had been coated with resin by the vacuum technique would have a significantly higher strength than laminates made by some of the other resin coating methods.

Wet strengths are significantly higher for all laminates molded at the lower temperature than for similarly fabricated laminates molded at the higher temperature; moreover, the difference due to temperature is about the same for all fabric finishes. The loss of strength caused by water immersion was significantly lower for laminates molded at the lower temperature when made of fabric with finishes 111 and 112; a possible exception to this exists for laminates prepared by resin coating method 2 for which the loss of strength appears to be about the same for the two molding temperatures. The loss of strength of laminates made of fabric with finish 114 and molded at the two temperatures was essentially the same.

No statistically significant differences are in evidence between the specific gravities of the laminates cured at the different temperatures. In most cases the laminates cured at the lower temperature had slightly higher resin contents than those cured at the higher temperature. Statistically, the evidence is not conclusive.

The laminates cured at the lower temperature generally had lower calculated voids contents than those cured at the higher temperature. While some of this effect may be due to the change in the density of

the resin due to loss of styrene, other explanations need consideration. The difference in the voids content of laminates cured at the two temperatures and made of fabric that was resin coated by methods 3 and 5 is smaller than the difference in the voids content of the laminates cured at the two temperatures and resin coated by method 1. In method 3 considerable air is allowed to escape from the pack of coated fabric because of the length of time allowed for the air to come to the surface before the resin is cured. In method 5 most of the air is removed by the vacuum. In resin coating method 1 large amounts of air are mechanically trapped in the laminate. It might be expected that laminates coated by method 1, owing to the additional expansion of the trapped air at the higher cure temperature, would show a larger difference in voids content for the two cure temperatures than would laminates prepared by methods 3 and 5. There is some indication in the data to support this interpretation, but the evidence is not conclusive.

The dry strengths were significantly different for the three fabric finishes and were as follows in decreasing order of strength: finish 111, 114, and 112. Laminates made of fabric with finish 114 had significantly higher wet strength than did laminates made of fabric with finishes 111 and 112. The effect of fabric finish on percentage loss of strength due to water immersion is considerable and increases in the following order: finish 114, 112, and 111.

Laminates made of fabric with finish 112 had the highest specific gravity; laminates made of fabric with finish 111 were lower in specific gravity; and laminates made of fabric with finish 114 had the lowest specific gravity. The differences in the specific gravities of the laminates made of fabric with the different finishes were generally small but statistically significant when considered in groups.

The average resin content of laminates made of fabric with finish 114 was 45.3 percent; of laminates made of fabric with finish 112, 41.8 percent; and of laminates made of fabric with finish 111, 43.6 percent. The differences in the resin content of these groups of laminates were statistically highly significant. It may be noted that an inverse correlation exists between the average resin content for a fabric finish and the corresponding average specific gravity.

The voids content of the laminates made of fabric with finish 112 was the lowest, while that of laminates made of fabric finish 111 was the highest.

Selectron 5003

The results of the flexural-strength tests on the laminates made with Selectron 5003 are presented in table III. The specific gravities,

resin contents, and volumes of the voids of the laminates are reported in table IV.

Both the dry strength and the wet strength of laminates prepared by resin coating method 2 are significantly lower than corresponding values obtained on laminates made by the other methods. Methods 1 and 5 tend to yield laminates of higher dry strength than do the other methods, but they do not show the same effect for wet strength. There were no consistent effects of coating method on loss of strength upon immersion in water.

No significant effect of resin coating method on the specific gravity is evident.

The resin content of the group of laminates made from fabrics that were coated with resin by method 2 and cured at the lower temperature was significantly different from that of the other groups of laminates. This group of laminates had the highest resin content, 51.8 percent, which is about 3 percent more than that of the other laminates.

As indicated in the discussion on laminates bonded with the Laminac resin, the voids calculations are biased since, in these resin coating methods, the styrene content of the copolymer resin was changed. Accordingly, no statistical analysis was made of the voids data.

The effect of temperature of cure on the strength was about the reverse of the effect observed in the laminates bonded with the Laminac resin. For both dry and wet strengths, laminates cured at the higher temperature showed significantly higher values than those molded at the lower temperature in all cases. There was some evidence that the percentage loss of strength upon water immersion was higher for laminates cured at low temperature as compared with those cured at the high temperature.

There is no difference in the specific gravities and resin contents of the laminates molded at the two temperatures with the exception mentioned above for laminates made by coating method 2.

CONCLUSIONS

From this investigation of the influence of some resin coating methods and other variables on the properties of glass-fabric laminates bonded with unsaturated polyester resins, the following conclusions may be drawn:

1. There is no consistent effect of resin coating method on the flexural-strength properties of laminates bonded with the Laminac resin. For laminates bonded with the Selectron resin both the dry and the wet strengths obtained with method 2 (use of a dilute solution of resin) were significantly lower than values obtained by the other methods.

2. There is considerable interaction between the resin coating methods and the temperatures of cure in laminates bonded with Laminac 4126. In resin immersion and vacuum impregnation the dry strengths of laminates cured at the two temperatures are essentially the same; for the other coating methods laminates molded at the lower temperature have greater dry strength than do those molded at the higher temperature.

3. For the laminates bonded with Laminac 4126 resin at the lower temperature the wet flexural strength is consistently higher than for laminates cured at the higher temperature, irrespective of resin coating method.

4. With Selectron 5003 resin the dry and the wet strengths were higher for laminates molded at higher temperature than for those molded at the lower temperature.

5. For laminates bonded with Laminac 4126 resin the strength properties were affected by fabric finish. In order of increasing value they were as follows: dry strength, 111, 114, and 112; wet strength, 111, 112, and 114; and percentage loss of strength, 114, 112, and 111.

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APPENDIX

STATISTICAL DESIGN AND ANALYSIS

Design of experimental program.- The main objective of the study was a comparison of five resin coating methods. In order to obtain results of more general validity, two further factors were introduced: fabric finish and method of cure. Three fabric finishes were included and two methods of cure, namely, a low-temperature slow cure and a high-temperature rapid cure. This three-factor study was made with one resin brand, Laminac 4126. In addition, a more limited experiment was made using a different brand of resin, Selectron 5003, of the same type and including as factors all the above variables except fabric finish.

In order to eliminate biases, the following steps were taken:

(1) The glass fabric used in both experiments was the same, and the pieces of fabric required for the fabrication of the various panels in both experiments were randomized before assembly of the panels.

(2) Resin of the type used here is subject to aging in a matter of months, the duration of the study. Accordingly, the preparation of the panels bonded with Laminac resin was carried out in three successive series, such that each series included one panel for each combination of the three factors, coating method, fabric finish, and method of cure. With the Selectron resin, only two series of panels were made.

(3) The order of fabrication of the panels within each series was randomized, and so was the order of testing.

(4) On each panel measurements of each property were made on four specimens for the flexural properties and on eight specimens for the other properties.

Method of analysis.- Analyses of variance were made for each property in order to determine:

(a) Specimen-to-specimen variability within a panel
(b) Panel-to-panel variability for each factor combination
(c) Effect of various factors and their interactions

A preliminary analysis, shown below, was made for the dry-flexural-strength data with the Laminac resin laminates to determine whether there was a series-to-series variability:

Source of variability	Degrees of freedom	Mean square, $(10^3$ lb/in.$^2)^2$
Treatment (T)	29	35.1
Series (S)	2	15.0
S × T	58	11.8
Total	89	

The analysis, based on panel averages, shows no such variability. Accordingly, all subsequent analyses of the Laminac laminate data were made ignoring series-to-series variability. Table V contains a summary of the analyses made on these data.

The Selectron laminate data showed a significant difference between the results obtained for some properties in the two series. The analyses made on the Selectron laminate data are summarized in table VI.

After obtaining the analysis of variance for each property, the individual data were examined to detect the particular combinations of factors which gave rise to significant main effects or interactions. The statements made in the paper regarding such effects are the result of this detailed study of the data.

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TABLE I.- FLEXURAL-STRENGTH PROPERTIES OF GLASS-FABRIC LAMINATES BONDED WITH LAMINAC 4126 RESIN

[Values reported are averages obtained with 12 specimens taken equally from triplicate panels molded at each combination of variables]

Resin coating method[a]	Fabric finish					
	111		112		114	
	Cure condition[b]		Cure condition[b]		Cure condition[b]	
	A - Low temperature	B - High temperature	A - Low temperature	B - High temperature	A - Low temperature	B - High temperature
	Flexural strength, dry, psi					
1	46,700	42,600	43,700	40,500	46,400	41,400
2	44,200	36,400	37,700	33,300	44,400	39,500
3	44,200	48,200	40,200	40,400	47,800	43,800
4	47,800	46,900	38,700	36,300	42,700	39,800
5	45,400	47,100	40,300	40,200	44,400	43,300
	Flexural strength, wet, psi					
1	25,600	21,300	27,700	21,000	36,900	31,100
2	23,300	20,700	22,300	19,400	36,800	34,000
3	23,300	19,900	29,200	21,300	38,200	33,800
4	23,800	19,300	25,700	18,300	34,600	30,700
5	26,300	20,100	26,300	21,400	35,300	32,800
	Loss of flexural strength due to water immersion, percent					
1	45	50	35	48	20	25
2	47	43	40	41	17	14
3	47	59	27	47	20	23
4	50	59	34	49	19	23
5	42	57	35	47	21	24

[a]Resin coating methods are as follows: (1) Roller coating, (2) application of dilute solution of resin, (3) resin immersion, (4) styrene coating, and (5) vacuum impregnation. For more detailed description, refer to text.

[b]Cure conditions are as follows: (A) 160° F for 48 hr; (B) 235° F for 2 hr.

TABLE II.- SPECIFIC GRAVITY AND RELATED PROPERTIES OF GLASS-FABRIC LAMINATES BONDED WITH LAMINAC 4126 RESIN

[Values reported are averages obtained with 12 specimens taken equally from triplicate panels molded at each combination of variables]

Resin coating method[a]	Fabric finish					
	111		112		114	
	Cure condition[b]		Cure condition[b]		Cure condition[b]	
	A - Low temperature	B - High temperature	A - Low temperature	B - High temperature	A - Low temperature	B - High temperature
	Specific gravity					
1	1.65	1.63	1.70	1.67	1.64	1.64
2	1.66	1.62	1.68	1.66	1.63	1.63
3	1.64	1.66	1.69	1.68	1.64	1.63
4	1.65	1.63	1.69	1.69	1.63	1.62
5	1.63	1.65	1.68	1.69	1.63	1.62
	Resin content, percent by weight					
1	43.8	42.5	42.6	40.4	45.1	43.0
2	44.2	46.6	43.1	43.7	47.1	46.2
3	43.5	42.1	41.5	42.2	45.4	45.5
4	43.6	42.2	40.5	40.4	45.4	44.0
5	44.3	43.7	42.2	41.4	45.7	45.8
	Voids content, percent by volume					
1	0.42	2.49	-0.37	0.49	-0.05	1.77
2	-.59	-.53	-1.05	-.23	-.64	-.36
3	1.03	.93	-.16	.18	.12	.51
4	.81	1.97	.32	1.51	.37	1.90
5	.36	.29	-.06	.15	.22	.60

[a]Resin coating methods are as follows: (1) Roller coating, (2) application of dilute solution of resin, (3) resin immersion, (4) styrene coating, and (5) vacuum impregnation. For more detailed description, refer to text.

[b]Cure conditions are as follows: (A) 160° F for 48 hr; (B) 235° F for 2 hr.

TABLE III.- FLEXURAL-STRENGTH PROPERTIES OF GLASS-FABRIC LAMINATES BONDED WITH SELECTRON 5003 RESIN

[Values reported are averages obtained with eight specimens taken equally from duplicate panels molded at each combination of variables. Finish on glass fabric was 114]

Resin coating method[a]	Cure condition[b]	
	A - Low temperature	B - High temperature
Flexural strength, dry, psi		
1	46,100	51,200
2	40,800	46,200
3	45,200	47,600
4	42,100	49,400
5	46,000	51,400
Flexural strength, wet, psi		
1	35,800	41,100
2	29,700	38,100
3	36,400	40,200
4	33,800	42,500
5	36,200	40,800
Loss of flexural strength due to water immersion, percent		
1	22.3	19.7
2	27.2	17.8
3	19.9	15.4
4	19.6	13.9
5	21.6	20.6

[a]Resin coating methods are as follows: (1) Roller coating, (2) application of dilute solution of resin, (3) resin immersion, (4) styrene coating, and (5) vacuum impregnation. For more detailed description, refer to text.

[b]Cure cycles were as follows: (A) 105° F for 24 hr; (B) 235° F for 1 hr.

TABLE IV.- SPECIFIC GRAVITY AND RELATED PROPERTIES OF GLASS-FABRIC LAMINATES BONDED WITH SELECTRON 5003 RESIN

[Values reported are averages obtained with eight specimens taken equally from duplicate panels molded at each combination of variables. Finish on glass fabric was 114]

Resin coating method[a]	Cure condition[b]	
	A - Low temperature	B - High temperature
Specific gravity		
1	1.68	1.68
2	1.64	1.68
3	1.66	1.66
4	1.66	1.66
5	1.66	1.66
Resin content, percent by weight		
1	47.5	47.2
2	51.8	47.9
3	48.1	48.6
4	46.9	46.3
5	48.3	48.4
Voids content, percent by volume		
1	0	0.24
2	-1.20	-.41
3	.02	-.21
4	1.69	1.87
5	.02	.15

[a]Resin coating methods are as follows: (1) Roller coating, (2) application of dilute solution of resin, (3) resin immersion, (4) styrene coating, and (5) vacuum impregnation. For more detailed description, refer to text.

[b]Cure cycles were as follows: (A) 105° F for 24 hr; (B) 235° F for 1 hr.

TABLE V.- ANALYSES OF VARIANCE OF DATA ON LAMINATES BONDED WITH LAMINAC 4126 RESIN

Source of variability	Degrees of freedom	Mean square					
		Flexural strength, dry, $(10^3$ lb/sq in.$)^2$	Flexural strength, wet, $(10^3$ lb/sq in.$)^2$	Loss of strength, (percent)^2	Resin content, (percent)^2	Specific gravity	Voids, (percent)^2
Specimen within panels	(a)	2.3	0.9	(b)	0.5	0.0001	0.04
Panel-to-panel	60	43.8	21.9	28.	16.6	.0041	1.9
Coating method (M)	4	101.	26.	32.	156.	.0003	46.3
Fabric finish (F)	2	1,033.	4,247.	6,078.	774.	.1744	30.0
Cure (C)	1	528.	2,161.	1,131.	47.	.0008	98.0
M × F	8	55.	17.	34.	7.	.0029	3.1
M × C	4	90.	9.	87.	46.	.0005	9.8
F × C	2	16.	44.	250.	1.	.0006	.9
M × F × C	8	30.	10.	9.	9.	.0025	3.4

[a]270 for flexural strength, dry and wet, and 630 for resin content, specific gravity, and percent void.
[b]For this property the variate is a panel average.

TABLE VI.- ANALYSES OF VARIANCE OF DATA ON SELECTRON 5003 LAMINATES

Source of variability	Degrees of freedom	Mean square				
		Flexural strength, dry, $(10^3$ lb/sq in.$)^2$	Flexural strength, wet, $(10^3$ lb/sq in.$)^2$	Loss of strength, (percent)^2	Resin content, (percent)^2	Specific gravity
Specimen within panels	(a)	1.4	0.9	(b)	(c)	(c)
Panel-to-panel	9	10.	35.	17.	0.6	0.0001
Series-to-series	1	195.	128.	.1	1.1	.0002
Coating method (M)	4	75.	63.	24.	5.9	.0002
Cure (C)	1	530.	765.	107.	3.6	.0001
M × C	4	12.	20.	10.	3.2	.0003

[a]60 for flexural strength, dry and wet, and 140 for resin content and specific gravity.
[b]For this property the variate is a panel average.
[c]Not calculated.